TITAN AND VENUS: COMPARING ATMOSPHERIC ENTRY OF LARGE METEOROIDS.

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Summary. The preparation for the Cassini-Huygens mission gives an opportunity to revise the problem of an atmospheric entry and breakup of cratering meteoroids. Recently this question was extensively addressed in connection with Venera and Magellan missions to Venus and the Shoemaker-Levy-9 comet impact to Jupiter. We present the numerical modeling of the meteoroid's flight trough the atmosphere in comparison with more simple models. The simulation takes into account the brittle/ductile properties of the meteoroid material: the Grady-Kipp-Melosh model of tensile failure is accompanied by a simple model of the shear failure.

For a modern atmosphere of Titan and ice projectiles the observable deficiency of impact craters due to atmospheric shielding would be in the range of 6 to 8 km, where the number of craters would be twice smaller than for the airless Titan

The Numerical/Analytical Model. We used the Simplified Arbitrary Lagrangian Eulerian code (SALE) [1]. The detailed description of the numerical modeling is published in [2].

Melosh et al. [3] implemented the model for rate-dependent tensile strength [4] into the 2D SALE hydrocode. The extension of the model to calculate the atmospheric entry was described in [5] and in more details in [2]. We made an attempt to improve the shear strength model, taking into account a pressure-dependent shear strength (Coulomb-von Mises model) with the cohesion decreasing with damage.

We used the numerical results to simulate atmospheric entry of stony and icy bodies into atmosphere at Venus, Jupiter and Titan. Numerical results were used to parametrize analytical models of the "inertial survivability" [6,7,8,9]. The resulted improved analytical model of projectile deceleration and fragmentation was used to reproduce the Venusian size-frequency distribution and to predict the Titan one.

Sizes of meteoroid fragments. The Grady-Kipp model, implemented into the hydrocode gives the possibility to estimate the size-frequency distribution of fragments **IF** natural meteoroids have a Weibull-like distribution of inherent flaws. This "if" is very important as natural bodies may have quite different structure at the scale of 1 km and larger. Anyway up to now we have no alternative way to estimate the fragment sizes.

We estimated the fragment size for entry angles from 90 to 5 degrees for Venus (stony projectiles) and Titan (ice projectiles). Our results show that even on Venus the hydrodynamic modeling is on the limit of applicability: even the "perfect" meteoroid with the Weibull flaw distribution separated initially into relatively large blocks, which barely may be treated with an ordinary hydrocode. In contrast one needs to calculate separation of large blocks with atmospheric gas entry to newly formed fractures. This is a real challenge for future simulations of the atmospheric breakup.

The model shows also the increase of fragment size for oblique entry angles. At 5 degrees the characteristic stress rate is 10 times smaller than for a vertical impact, so according to the Grady-Kipp model one predicts approximately 5 times larger fragments. It is the real way to estimate the transition from the impact of a compact mass of small fragments for steep entry ("irregular craters") to the meteoroid disruption into several (2 to 6 largest according to the Venus experience - see [12]) large fragments which reach the surface with a possible secondary disruption and produce a strewn field

After these warnings we nevertheless use simplified hydrodynamic models to predict the size-frequency distribution of impact craters for Titan.

Impact crater size-frequency distribution.
Venus. We used the Magellan crater count to test the simplified model quoted above. We supposed the "average" impact velocity 19.1 km/s for Venus and the most probable projectile density equal to the target density (see [10] for details).

The size-frequency distribution of projectiles (mostly stony) is estimated from the lunar cratering records using the standard production cratering distribution derived by Neukum [10]. The application of the model gives results shown on Fig. 1, where the Magellan data are compared with the model distributions for decelerated rigid and deformed projectiles. The theory is not applicable for craters below 5 to 8 km in diameter, as small craters were definitely created by impacts of clusters of the projectile debris: most of these craters are strewn fields or so-called irregular crates [11, 12]

Titan. Proving applicability of the simple model with the Venusian crater population we made a similar prognosis for the modern atmosphere of Titan, supposing all impactors are made of ice and enter the atmosphere at 45 degrees with the velocity of 15 km/s. Following [13] we assume the absence of the crater widening due to collapse. The result is shown on the Fig. 2 where we compared size-frequency distributions for (i) airless Titan, (ii) cratering curve deflection due to deceleration of rigid meteoroids, and (iii) the application of the simple approximation of the meteoroid breakup.

The input size-frequency distribution was the lunar-like. Although the real shape of the size-frequency projectile distribution of projectile may be quite different, the usage of the non-power law have an intention to outline the possibility of the non-power low for Titan-impacting projectiles especially if the significant proportion of projectiles derived from a collisional evolution of the Kuiper belt objects [17]. To simplify the comparison we plot Titan curve at the same absolute level of the crater areal density as on Venus (Fig. 2).

Discussion. Engel et al. [13] discuss the impact cratering process on Titan in view of the Cassini-Huygens mission. They address important points in the analysis of the Titan surface IR and radar imagery like the probable atmospheric evolution, the hypothetical bombardment with Hyperion parent body fragments etc. The paper by Lorenz [14] also covers a wide range of predictions for the morphology and morphometry of impact craters and impact-related features (crater chains, airbursts, parabolas etc.).

In completing the list of projectile types on [13] one has to take into account that some Kuiper belt objects may be similar to large planetary bodies like Pluto and Charon (see, for example, [15. 16]). These objects could have a thermal evolution with differentiation. At least part of meteoroids originated from the Kuiper belt may be fragments of these large and relatively dense bodies, resulted from the collisional evolution of the Kuiper belt objects [17].

For ice bodies our results look quite different in comparison with the prognosis by Engel et al. [13]: the “turndown” crater diameter seems to be 2 to 4 times smaller for a modern atmospheric pressure. This tendency seems to be the same for more dense ancient atmosphere supposed by Lunine (see [13]). For less dense ancient atmosphere supposed by McKay et al. [18] we can predict more strewn fields that one observed on Venus. As it was mentioned before, strewn field formation needs a separate extended discussion

The qualitative predictions of the possible parameters of the impact crater population on Titan definitely needs much more study

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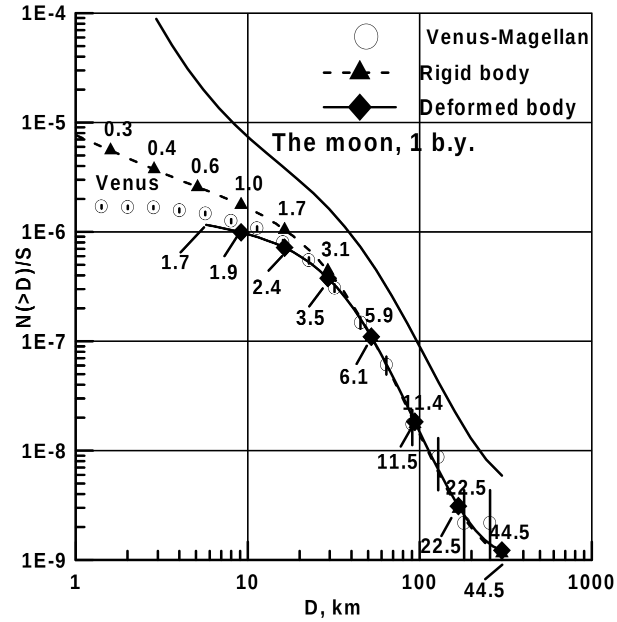

Fig.1. The estimated size-frequency curve for Venus in comparison with the Magellan data. Numbers are the projectile diameters for 45 degree impact of stony bodies at initial velocity of 19 km/s.

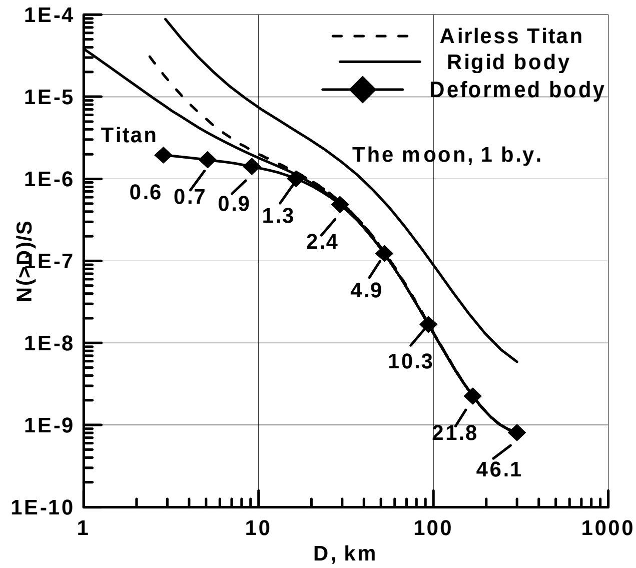

Fig. 2. The estimated size-frequency curve for Titan. Numbers are the projectile diameters for 45 degree impact of ice bodies at initial velocity of 15 km/s.